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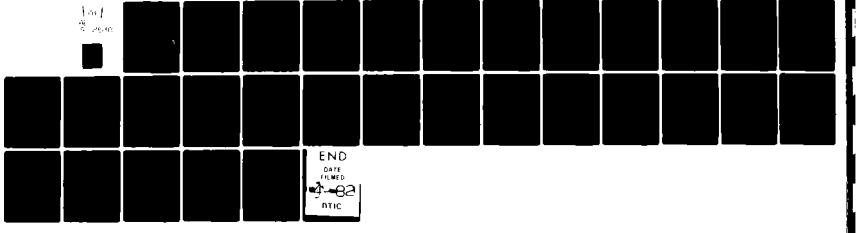

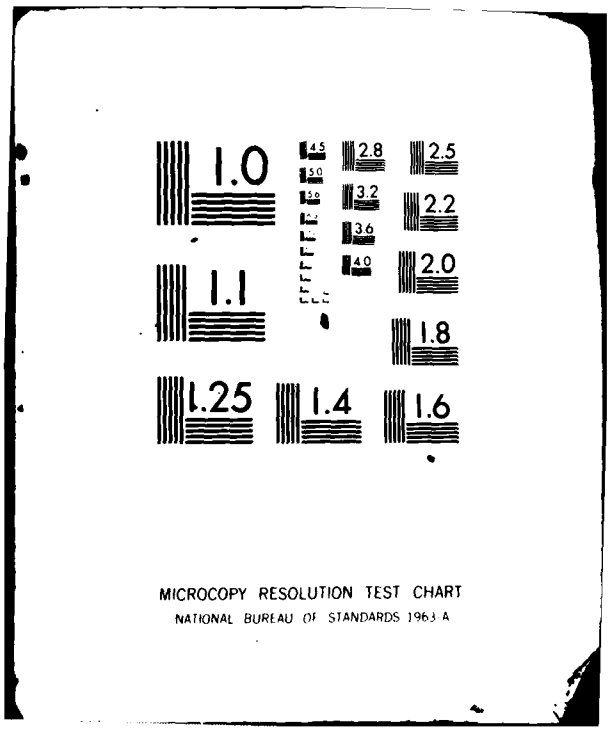
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Jonathan T. Grudin

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Central Control of Timing in Skilled Typing

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Abstract

The timing of keystrokes during errors in skilled transcription typing suggests central control of timing for two-letter sequences. I find that letter transpositions are performance errors, and the timing of interstroke intervals in these errors is closely correlated with the pattern found in the same words typed correctly. This and other aspects of the timing argue against both a distributed processing model with single-character units and a pure metronome model. For these two-character sequences, timing seems to be controlled by signals issued generally, rather than to a specific finger.

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Central Control of Timing in Skilled Typing

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Timing in Models of Skilled Typing

Models for the timing of keystrokes in typing vary in the degree of central control over the motor process. In this paper, I consider three models: (a) a pure "metronome" model; (b) a model primarily reliant on distributed control; and (c) a model with centralized control over the timing of movements within sequences of a few letters or a word. Following a brief discussion of the models, I describe evidence from one common typing error, the transposition. First, I argue that transpositions are performance errors. Then I establish that the timing, the pattern of interstroke intervals, in a word typed correctly is largely preserved during a transposition. This suggests that the timing is generated centrally for that sequence.

Metronome Model

A metronome model posits a regular, internal "clock" whose "ticks" signal the initiation of the typing of each key. Precise control of this nature is required by pianists, for example, and is often urged upon beginning typists. However, although expert typists are more regular in their typing than beginners, many keystrokes show consistent deviations from the mean. Thus, for one typist who averages 184 msecs per keystroke, the median interstroke intervals for typing "the" (with following space) are 124, 134, 119, 171 msecs, respectively. It is difficult to imagine a 184 msec metronome operating here. Similar considerations led Shaffer (1973, 1978) to abandon a pure metronome model for one in which a metronome beat is either modulated or replaced by timing information in structural strings representing some sequences to be typed. Gentner, Grudin, and Conway (1980) and Gentner (1981a) presented evidence that the timing for a given keystroke is most dependent on the physical constraints presented by the keyboard, the hand, and the context preceding the letter being typed. In addition, digraph frequency influences the interstroke interval (Grudin, 1981). Given these data, a model based solely upon a precise internal metronome cannot be supported.

Distributed Processing Model

Rumelhart and Norman (1982) proposed a distributed control model that has no central processor controlling either movement or timing. A keystroke is triggered when a letter-representation has a sufficiently high level of activation and the finger has approached the key. There is no central pacer, and there is no central representation of the timing pattern for a sequence of letters. The pattern of interstroke intervals emerges epiphenomenally and depends upon how long the fingers take to get into position and reach full activation.

In the computer simulation of this model, the text to be typed is parsed into words and then letters, each of which is activated. To insure that the letters are typed in the correct order, each letter inhibits the following letters in the sequence to be typed. When a

letter has been typed, this inhibition is released, allowing the next letter to rise to full activation. Once the initial activations and inhibitory connections have been established, there is no further central involvement.

The motor sequences to type the different letters are all initiated simultaneously. The activations for the letters are summed to control the hands and fingers. (Thus, more strongly activated letters are favored.) When two letters share common movements, they speed the finger and hand motion. When movements conflict, the motion is slowed.

Consider the typing of the word wrung. (See the keyboard layout in Figure 1.) The fingers have a shared interest in moving toward the top row to type the w and r, so the activations pool in moving the left hand up. A conflict occurs between the typing of u and n (both typed by the right index finger), resolved by a weakened movement toward the letter u. When a hand or finger has not been used for a while, it has more time to position for the next letter. Thus, while the right hand is typing un, the left hand has considerable time to get to the g, so the g is typed with a small interstroke interval. This is consistent with data showing smaller interstroke intervals for across-hand keystrokes (Shaffer, 1978). In addition, both data and theory show co-occurrence or overlapping of the finger movements of successive keystrokes (Olsen & Murray, 1976; Gentner, Grudin, & Conway (1980).

The simulation model accounted for the known typing phenomena very well. Shaffer (1978) found that when the hand used on successive keys alternated, there was a negative correlation of successive keystroke times and a positive correlation of keystrokes two away. From this, he concluded that there is a "super-ordinate pacing element" in response output. However, the distributed control model of Rumelhart and Norman produced the same pattern of correlations with no central pacing element.

Models with Sequence-Specific Timing

A third model postulates that keystroke timing is controlled by central patterns of timing impulses that are specific to the word or letter-sequence to be typed (Terzuolo & Viviani, 1980). This differs from the previous model in that there is continual central control through the output process, and the timing pattern is actually represented in the system, rather than emerging from movement constraints.

The possibility that "hierarchies of habits" might be formed in learning dates back at least to Bryan and Harter (1897, 1899), who claimed evidence for them in learning curves for receiving telegraphy code. They did not find corresponding evidence in learning to send code, however. There are several possible mechanisms for an intrinsic or centrally-produced timing pattern. The timing pattern might be word-specific and stored, to be accessed with the word. Alternatively, it might be generated "on the fly" each time a word is to be typed.

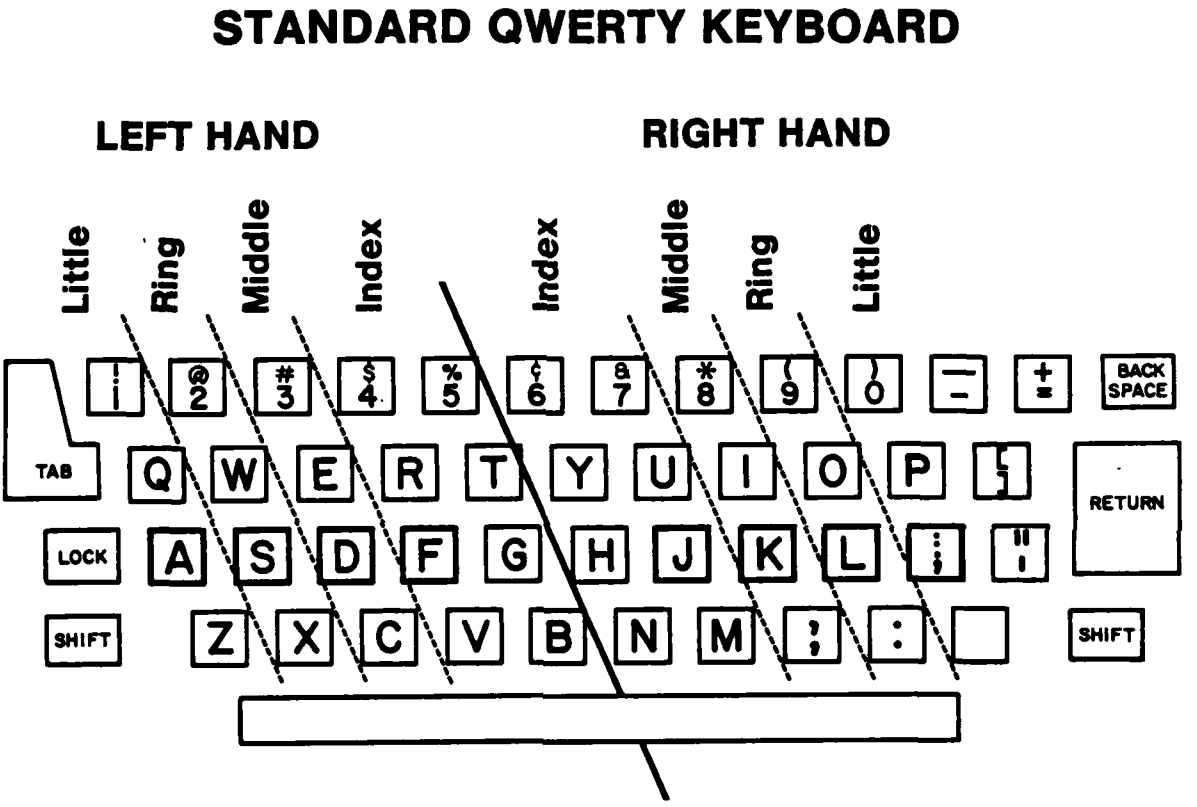

Figure 1. The standard typewriter keyboard.

Also, each timing or "trigger" pulse might be directed toward a specific key, or there might be a general pulse that affects only a sufficiently activated or prepared key. Such a trigger pulse would not be a signal to begin movement toward the key. This movement is highly variable and can end with a prolonged hovering above the key to be struck (Gentner, Grudin, & Conway, 1980). The pulse would instead signal the final downstroke resulting in the recorded keystroke. Nevertheless, the time between the signal to strike and the keypress itself may vary, dependent, for example, on how close the finger has approached the key.

Terzuolo and Viviani (1980) argue for word-specific timing patterns. Repeated typings of the same word, they claim, show a single timing pattern, with interstroke intervals varying among examples only by a multiplicative rate parameter affecting all intervals proportionally. However, in a more detailed study of several transcription typists, Gentner (1981b) found no evidence for such a rate parameter. He also showed that the conclusions of Terzuolo and Viviani (1980) are influenced by an artifact of their scaling procedure.

Nevertheless, these negative findings do not preclude the possibility that timing pulses specific to a given sequence of letters are produced centrally. These might be stored internally or generated as part of the output process. This paper presents evidence for such timing patterns for two-letter sequences. The data provide further evidence against a pure metronome model, and the distributed control model of Rumelhart and Norman (1982) must be modified to account for them.

Transposition Errors

Method

Five professional typists transcribed six magazine articles totaling approximately 50,000 characters on a computer terminal with which they were familiar. The text was presented as double-spaced typed copy on individual sheets of paper. Keypresses and the corresponding times were recorded by a microcomputer.

Here I examine the 116 transposition errors produced by these five typists. In particular, I contrast the timing of the keystrokes in the errors with the timing of the same words typed correctly.

A note on terminology. I designate the characters that end up being transposed as C1 and C2, in the order of their appearance in the correctly spelled word. Thus, for the error also -> aslo, C1 is l and C2 is s. Because I am interested in the positions immediately before and immediately following the error as well, I designate these as C0 and C3, respectively. Therefore, in this example, C0 is a and C3 is o. In the example of of -> fo, C1 is o, C2 is f, and C0 and C3 are both "space." With this notation, a transposition may be described by "C0 C1 C2 C3 -> C0 C2 C1 C3."

Where in Processing Do Transpositions Occur?

Transcription typing involves both perception and motor control. Transpositions do occur in immediate recall of item lists (e.g., Koestler & Jenkins, 1965; Conrad, 1965), and some letter reversals in typing from text might possibly occur from errors of perception or memory. However, typists frequently make transposition errors while typing generatively; that is, typing without a text, situations in which perception plays no role. Moreover, because perceptual and memorial processes are biased toward words, perceptual and memorial errors should lead to the typing of wrong words. However, 114 of the 116 transposition errors produced nonwords, usually unpronounceable (such as thme for them, rpinciple for principle). The errors occasionally involve punctuation (exampl,e for example,) or spaces (aj ob for a job). These errors are unlikely to be perceptual or memorial. Healy (1976,1980) has shown that we tend to read common words as units, yet in transposition errors it is often common words that are typed as nonsense strings (adn for and, teh for the).

Only if the typists are processing the text as letter strings, rather than individual words, could these errors have arisen in perception or memory. I established that the typists processed the prose for lexical, syntactic, and perhaps semantic information as they typed. At three separate locations in the copy from which they typed, the wrong English word (accidentally) appeared, differing by one letter from the word that appeared in the original magazine article. Table 1 presents the text as it should have read and as it did appear. In 11 of the 15 times the typists encountered these words, they corrected the text. There was a discernible pause prior to making the correction only once.

Most transposition errors involve fingers on different hands (78% in our corpus, with chance being 53%, the percentage of across-hand digraphs). Almost none are within finger (2%, where 10% would be expected by chance). This, too, suggests that transpositions are performance errors.

In another study, I examined videotape records of the fingers for 43 transposition errors. In 63% of the cases, the first finger to strike a key made the first motion toward the key. I performed the same analysis on the two letters in the same positions in a set of correctly typed words matched for length with the error words, with the further requirement that the two correctly typed letters match the transposed letters as to whether they were within-finger, within-hand, or across-hand. I found that for 74% of the correctly typed pairs the first finger to strike moved first. Thus, although transposition occurs in performance, it usually has occurred before the actual action.

Table 1

Error Correction in Transcription Typing

Instance 1

Original: To meager supplies of inferior graphite...

Text: To meager supplies or inferior graphite...

Instance 2

Original: ... precisely one ounce of gold.

Text: ... precisely one once of gold.

Instance 3

Original: ... and trace the fatigue to its source...

Text: ... and trace the fatigue to is source...

Instance	Typed	
	as read	corrected
1	1	4
2	2	3
3	1	4

Are Letter Reversals Simply 'Noise'?

There is variability in the interstroke interval in repeated typings of a passage, where context and frequency effects are of course controlled. Perhaps this is the origin of transposition errors. One keystroke might occur more slowly than usual and the next keystroke more quickly than usual. Suppose that in typing *of* the right hand was out of position, delaying the ring finger's arrival at the *o*; the result might be *fo*. This is consistent with the evidence that transposition errors tend to occur across-hand, particularly given that two or more fingers, usually of different hands, are often simultaneously in motion (Olsen & Murray, 1976; Gentner, Grudin, & Conway, 1980).

However, it is possible to reject this variability as the complete explanation of transpositions. Consider the distributions of *o* and *f* keystroke times in *of* typed correctly. As seen in Figure 2, there is an overlap. The fastest time for an *f* is shorter than a long *o*. If *fo* results from a fast *f* coinciding with a slow *o*, we can estimate the interval between the two letters -- it should be short, within 40 msec (220 - 180). The actual interval recorded (81 msecs) was twice that, suggesting that more was involved than randomness in the normal execution of the keystrokes.

Analysis of the Transposition Error Corpus

The remainder of this paper is devoted to a detailed examination of the interstroke intervals recorded for transposed letters. It verifies the phenomenon just described -- the timing pattern has no unusually small interstroke intervals -- and goes further, finding evidence that the timing pattern is generally close to that found in the same word typed correctly. This suggests that a timing mechanism might generate a series of trigger pulses specific to a sequence, independent of the movement toward the specific keys. The timing pattern is preserved even when the keys are typed in the wrong order. The result runs counter to the predictions of the pure metronome model and of the Rumelhart and Norman (1982) model, at least as it now stands.

This section begins with an example that is representative of the whole corpus. Then I present the general data, and discuss the implications for the models. A final correlational study permits further restriction of the set of workable models.

A Representative Example: Teh

The single most common transposition resulted in typing *Teh* instead of *The*. In Table 2 are the median interstroke intervals for both correct typings of the word, and for the errors. There is not an unusually short interval between the transposed letters. The keystroke interval distribution for the second and third letters seems to be the same for *The* and *Teh*. The interval between typings of *h* and *e* is positive when *e* follows *h* and negative when the two are transposed. (Figure 3). Rather than a continuous distribution including low negative values

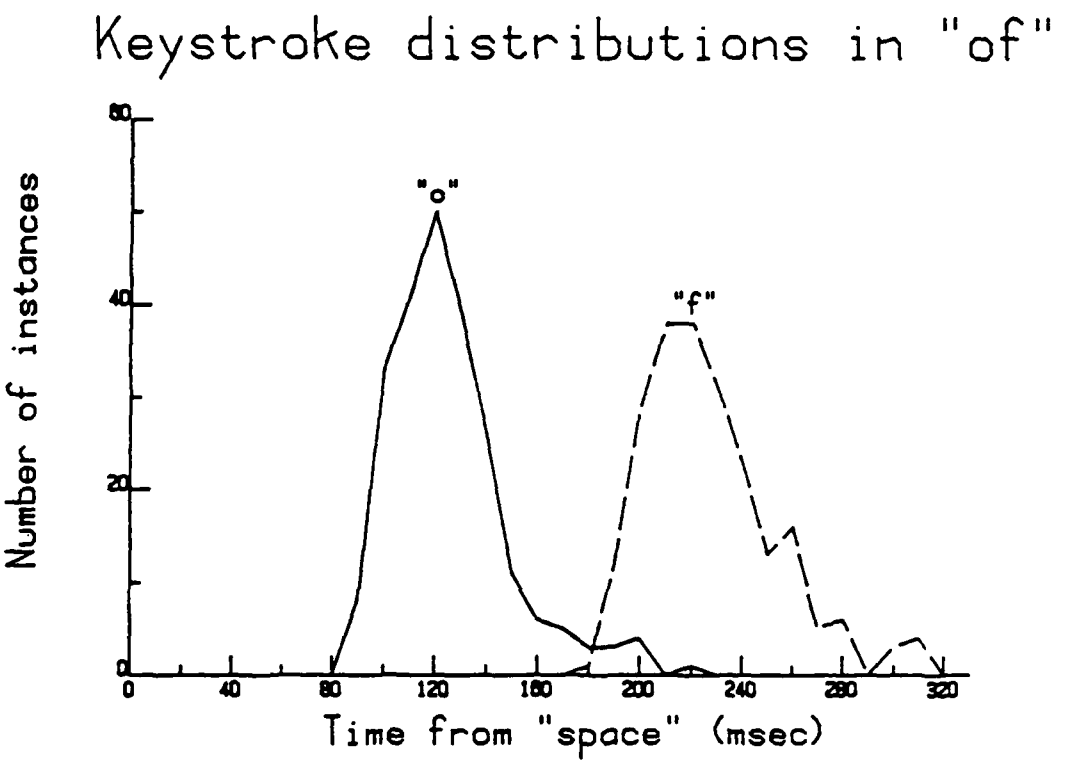

Figure 2. Distributions of keystroke delays from the typing of the space preceding the word of. A slow o could come in up to 40 msecs later than a fast f.

Table 2

Transposition of "THE" (T3)

Target word	Typed correctly	Typed with transposition e-h
the	403	0
The	47	3

Median Intervals (msecs)

the	t-h	h-e
	95	84
The	T-h	h-e
	148	90
Teh	T-e	e-h
	164	71

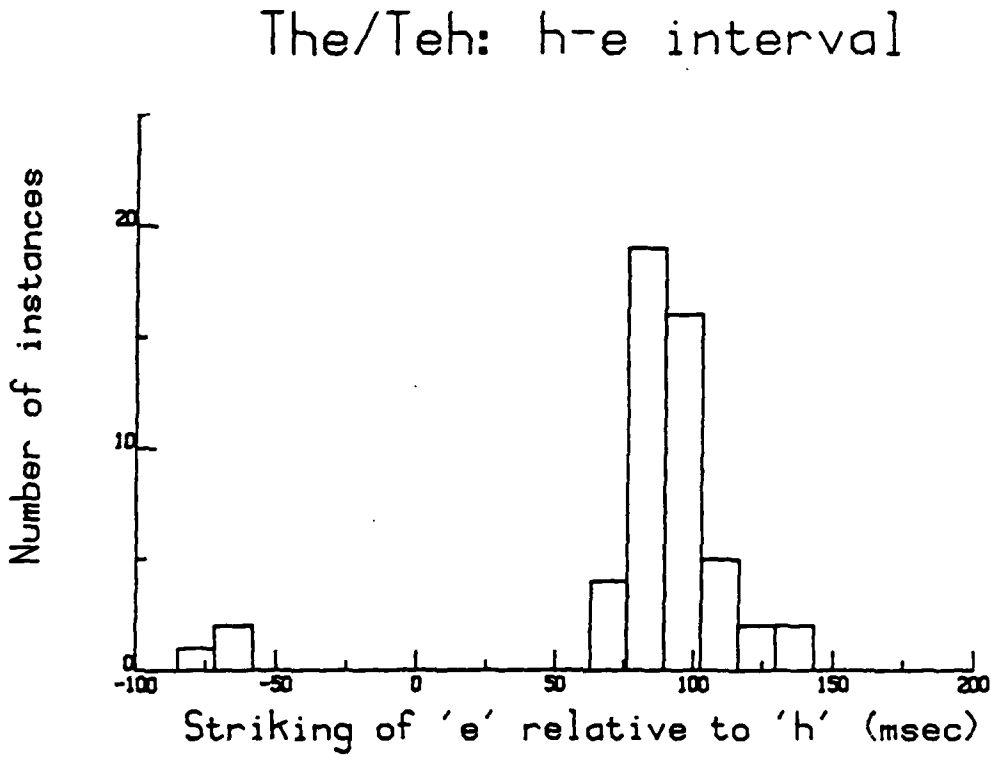

Figure 3. Distribution of intervals between typing the h and typing the e when trying to type the word The. The negative values on the left represent the transpositions Teh. The distribution is bimodal, not continuous.

for the errors, the data show a discontinuity. This is based on a small number of instances, but it is representative of the full set of transpositions, described below, which argue for timing patterns depicted in Figure 4.

The example of Teh affords us an insight into a possible mechanism contributing to transpositions. As indicated in Table 2 , the word the appears in the text over eight times as often as The, yet the error occurs only when the T is capitalized. To see why, consider the keyboard layout (Figure 1). The letters t and e are typed with the left hand, h with the right. The shift key in this case is typed with the right hand, pulling the hand far to the right, away from the h. This "spatial dislocation" of the hand might result in the right index finger taking longer than usual to arrive in place to strike the h. The e, however, typed by the unaffected left hand, would be ready to go on schedule.

I tested the hypothesis that such positional dislocations contribute to transposition errors by examining all transpositions occurring in words preceded by those keys that would draw away one hand: shift, carriage return, and a backspace. Most transposed pairs are typed by different hands. I predicted that the delayed letter, C1, would be typed by the hand that had moved out of position. The data strongly support this hypothesis ($p < .01$ by sign test), as shown in Table 3. In most cases C1 is typed by the hand that strikes the shift key (or CR or BS). The first letter of the transposition, C2, is typed by the hand that was unaffected by the earlier movement. Words that contained a transposition and that were followed by a carriage return or by punctuation did not show any effect.

Elsewhere I present evidence for and model another mechanism underlying some transpositions (Grudin, 1981). Nevertheless, hand mispositioning could be a factor in more errors than those described here. It is consistent with the prevalence of across-hand transpositions, and in our study of a high-speed film of an expert typist (Gentner, Grudin, & Conway, 1980), we concluded that timing differences in repeated typings of the same word are correlated with the initial position of the hands.

The General Results

In 74 instances, a typist typed the same word with and without a transposition error. I used these to examine the interstroke intervals for four character positions -- the positions involved in the error (C1 and C2), the preceding position (C0), and the following position (C3).

For each position I compared the keystroke times in the correct and incorrect typings of the word. To do this, I subtracted the times for the correctly typed word from the corresponding times for the word with the error. That is, Ci(error) - Ci(correct) for i = 0, 1, 2, and 3. I used median times where there were multiple typings of a word by the typist. Table 4 shows the minimum, median, and maximum of these interval differences for each position.

TIMING PATTERN IN TRANSPOSITIONS

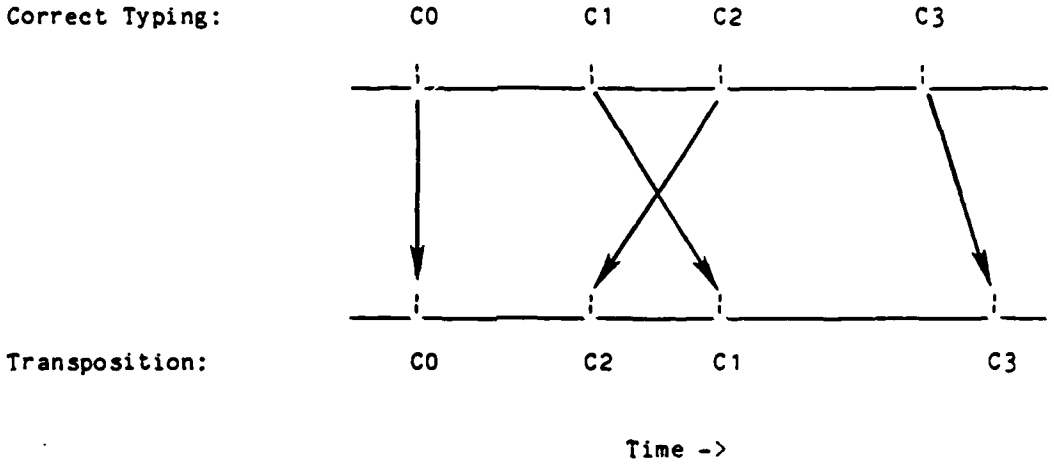

Figure 4. Comparison of the keystroke time patterns for a typical sequence typed correctly and typed with a transposition. The timing is largely preserved until the delay in the letter following the error.

Table 3

Consistency with Hand Dislocation Hypothesis:

Delayed letter in transposition is typed by hand pulled away by the keystroke preceding the word.

Words with transposition that were:	consistent	inconsistent	neutral
Preceded by shift or backspace (1)	9	1	0
Preceded by carriage return	6	1	2
Followed by punctuation	9	9	4
Followed by carriage return	9	8	0

Table 4

Interstroke Intervals in Transpositions (by position)
(msec)

Position	Min	Med	Max
	Interstroke Interval Differences (Error - Correct)		
C0	-515	-7	483
C1	-342	8	373
C2	-101	17	1386
C3	-136	86*	1960
	Excluding Hesitations (Intervals > 200 msec)		
C2	-101	0	190
C3	-136	38*	184
	Interstroke Intervals in Errors		
C0	62	148	1394
C1	64	172	572
C2	49	147	1578
C3	9	250	2219

*significantly greater than zero

If transposition errors were to be explained by a later-than-usual arrival of the first key, then C1(error) - C1(correct) should be high. If the second key were coming in more quickly than usual, C2(error) - C2(correct) would be negative. C2 was typically 17 msec greater in the error than in the correctly typed word. The key that should have been the first one typed was not just slightly delayed--it came in when the next key should have, or even later. Thus, when aslo was typed for also, the l was typed not just a little later than a typical l, but when the s normally would be typed.

However, there were several very long interstroke intervals for C2(error). This is indicated in Table 4 by the high values for the maximum difference. This could happen if the error was sometimes detected during execution and the typist paused. The distribution of C2 times is in Figure 5. They cluster below 190 msec, with several scattered above 400 ms. If we assume the long delays represent hesitations and exclude them from the calculation, we get the figures in the middle part of Table 4. The median difference for C2 is now zero--the time is the same for that letter position in the correct and in the transposed case. The timing of the word seems to have been preserved despite the error in key sequence.

Note that the position following the error is delayed in the error word. The distribution is shown in Figure 6). Even eliminating all intervals over 200 msec, the median difference stays significantly positive at 38 msec ($t(73) = 3.5$, $p < .001$).

The last four rows of Table 4 show the minimum, median, and maximum times found in typing the word, both correctly and in error. The unusually small C2(error) values predicted by the movement noise hypothesis are not present.

(Several small interstroke intervals occurred for C3 in the typing of one typist, T1. In each case, the letters typed in positions C1 and C3 in the error were typed by one hand, and the letter in position C2 by the other. Possibly this typist occasionally triggered two keystrokes simultaneously, one on each hand, and when the wrong one struck first, a transposition resulted.)

Discussion of the Models

Two of these results are salient to a discussion of the models: (a) transpositions occur as part of the response or output process; (b) the timing pattern, or sequence of interstroke intervals, is the same in the transposed positions as it would be had the word been typed correctly.

Distributed control models. A distributed control model with single keystroke motor response units, such as that of Rumelhart and Norman (1982), has difficulty. Without some central or general influence over timing, keystrokes occur in sequence as soon as they can. It is necessary to account for the delay in the second letter of a typical transposition. The Rumelhart and Norman model accounts for transpositions by

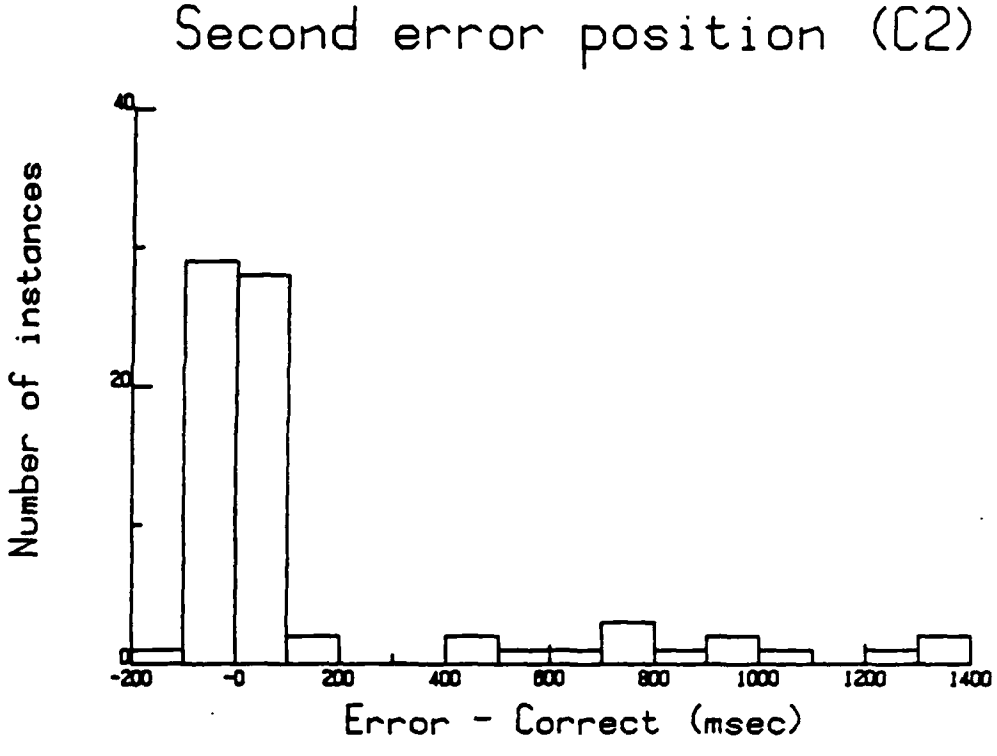

Figure 5. The distributions of interstroke interval differences for C2, the second letter position transposed in the error. The time for that position when it was typed correctly has been subtracted from the time in the error. This was done for each error and the resulting distribution is plotted. The values to the right represent hesitations during the error.

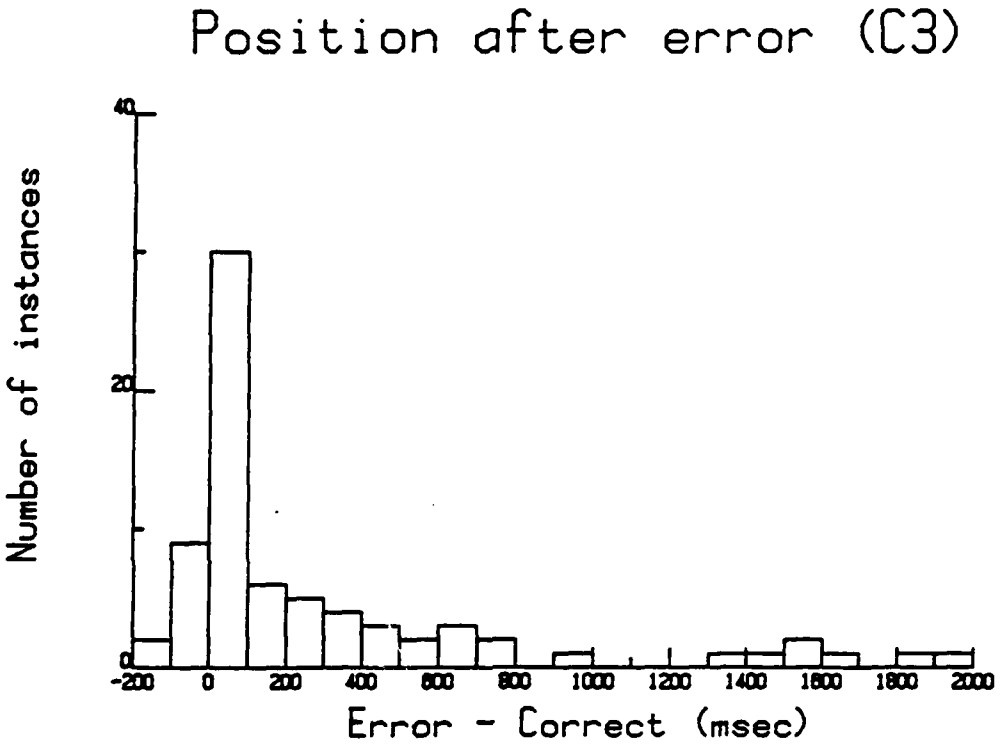

Figure 6. The distributions of interstroke interval differences for C3, the letter position following the transposition. The time for that position in the correctly typed word has been subtracted from the time in the error. This was done for each error and the resulting distribution is plotted.

allowing the activation value of letters to be noisy, and thus to fluctuate. Occasionally the wrong letter becomes the one with greatest activation. The simulation produces times for the second keystroke that are very small, often under 50 msec, values not encountered in this study. The short intervals could be eliminated from the model if the reversal occurred relatively early in the output process. For the Rumelhart and Norman model, this would be during the parsing of a word into letters, or during the establishment of inhibitory connections. This leaves three problems: (a) the prevalence of 2H transpositions is more difficult to explain; (b) some transpositions are affected by conditions arising later in the typing of the word, such as a hand being out of position; (c) it would lead to the timing of a transposed pair of letters resembling the timing of those letters in their final ordering more than the timing of the letters in their intended order, which I show below to be untrue.

The distributed processing model can handle these data if the basic response units includes two-letter elements. Even a single keystroke is a temporally organized set of motor commands. These can involve activity of various postural muscles before the finger, hand, and arm muscles (Lundervold, 1951). It is not a great extension of the control task to organize the actions for a pair of keys. Postural adjustments might be smoother if successive keystrokes are handled together.

Central timing models. The central sequence-specific timing pattern models can account for the data presented thus far. In this class of models, there are patterns of triggering signals specific to the sequence being typed. These trigger signals could be finger-specific. Alternatively, they might be hand-specific or even issued generally, the correct action being taken as a result of selective pre-activation. If issued generally, we would expect the same pattern of times whether or not an error occurred. If the trigger is finger-specific (or letter-specific), then switching two letters would result in switching the interstroke intervals. Thus we would expect there to be a difference on a given error word / correct word pair for the positions where the error occurred. For one position the difference would be positive, for another negative. But averaged over many different words, as done above, a difference of zero could emerge.

Selecting among Models: A Further Analysis

To distinguish further among these models, I eliminated items with hesitations of over 400 msec and examined the correlations of times in correct and erroneous typings. To understand the logic of this analysis, consider the time of the letter l in the transposition aslo for also. What might the time delay for typing the l in aslo be correlated with? There are at least three possibilities: (a) It might be correlated with the time to type l in also (a letter-specific correlation); (b) It might be correlated with the time to type s in also (a position-specific correlation); (c) It might be correlated with the time to type l in a normal sl sequence, as in words such as sleth, isle, and hassle (a context-specific correlation).

A pure metronome model offers no reason for the l time in aslo to be correlated with any particular time in also. A model that assumes a letter-specific (or finger-specific) timing pulse would predict a high letter-specific correlation of interstroke intervals. A model that posits the formation of a general pattern of triggering signals for the sequence to be typed might predict a position-specific correlation -- that l in aslo would be relatively highly correlated with the s in also. A model that placed the letter reversal very early in the output process would predict a high context-specific correlation.

To test these hypotheses I looked at correlations of interstroke intervals. There were too few data points from some typists to run individual correlations, so I had to pool data. Before doing so, times for each typist were normalized to eliminate any effect of speed differences among the typists. The correlations are shown in Figure 7. The data support position-specific timing. They provide no evidence for letter-specific timing. Thus there seem to be signals comprising the timing pattern that are not finger-specific, or even hand-specific.

There is also a high context-specific correlation for C1 but not for C2. This may be because most transpositions are across-hand, so the first interval is more often within-hand. Physical constraints imposed by within-hand movement may contribute to the high correlation of .67. The across-hand movement has little physical constraint.

These analyses suggest that there is some general timing pattern, and signals to strike keys are issued according to that pattern, but that when the letters are out of sequence, physical constraints on movement that arise from the error help determine the exact moment of the keypress.

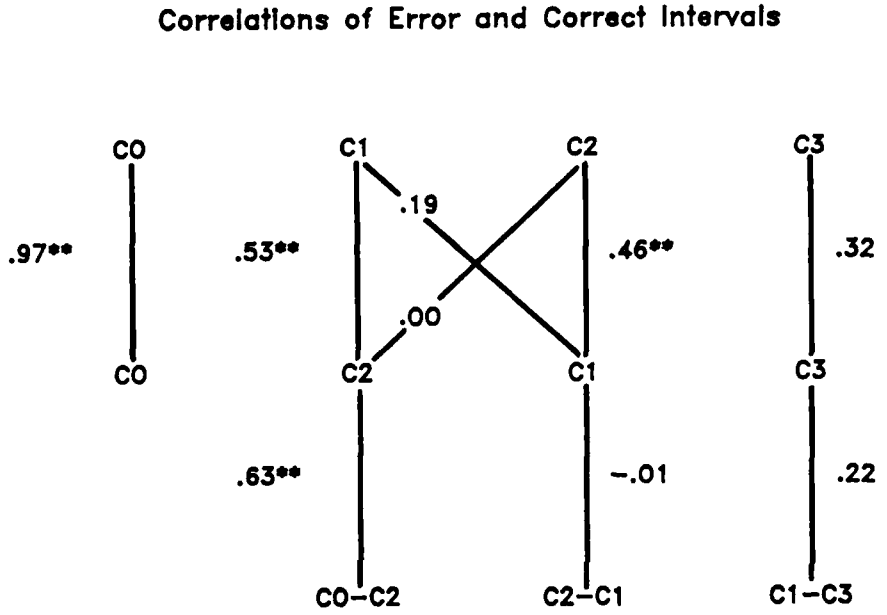

Figure 7. The correlations between times in words typed correctly and with a transposition error. Also included are median times as normally typed for the digraphs formed by the error. Position-specific timing and some context-specific timing are apparent.

REFERENCES

Bryan, W.L. & Harter, N. Studies in the physiology and psychology of telegraphic language. Psychological Review, 1897, 4, 27-53.

Bryan, W.L. & Harter, N. Studies on the telegraphic language. Psychological Review, 1899, 6, 345-375.

Conrad, R. Order error in immediate recall of sequences. Journal of Verbal Learning and Verbal Behavior, 1965, 4, 161-169.

Gentner, D. R. Skilled finger movements in typing (Tech. Rept.) La Jolla, Calif.: University of California, San Diego, Center for Human Information Processing, 1981a.

Gentner, D. R. Timing Patterns in Typing. Manuscript in preparation, 1981b.

Gentner, D. R., Grudin, J., & Conway, E. Finger movements in transcription typing (Tech. Rept. 8001). La Jolla, Calif.: University of California, San Diego, Center for Human Information Processing, 1980.

Grudin, J.T. The organization of serial order in typing. Doctoral dissertation, 1981, University of California at San Diego.

Healy, A.F. Detection errors on the word the: evidence for reading units larger than letters. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 235-242.

Healy, A.F. Proofreading errors on the word the: new evidence on reading units. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 45-57.

Koestler, A. & Jenkins, J. Inversion effects in the tachistoscopic perception of number sequences. Psychon. Sci., 1965, 3.

Lundervold, A.J.S. Electromyographic investigations of position and manner of working in typewriting. Acta Physiologica Scandinavica, 1951, 24, supplementum 84.

Olsen, R. A., & Murray, R. A., III. Finger motion in typing of texts of varying complexity. Proceedings, 6th Congress of the International Ergonomics Association, July, 1976, 446-450.

Rumelhart, D. E., & Norman, D. A. Simulating a skilled typist: A study of skilled cognitive-motor performance. Cognitive Science, 1982, in press.

Shaffer, L. H. Latency mechanisms in transcription. In S. Kornblum (Ed.), Attention and Performance IV. New York: Acedemic Press, 1973.

Shaffer, L. H. Timing in the motor programming of typing. Quarterly Journal of Experimental Psychology, 1978, 30, 333-345.

Terzuolo, C. A., & Viviani, P. Determinants and characteristics of motor patterns used for typing. Neuroscience, 1980, 5, 1085-1103.

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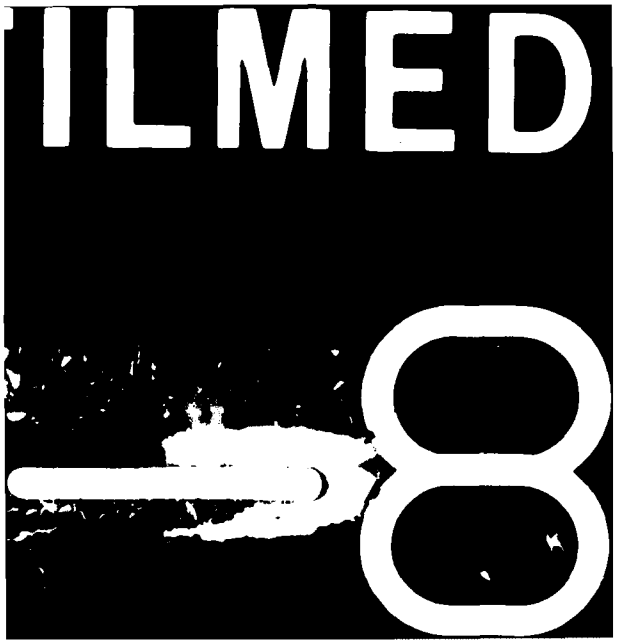
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